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CFD Calculations of the Air Flow Along a Cold Vertical Wall with an Obstacle

by

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ABSTRACT

In buildings with large glazed facades there may be problems with thermal discomfort due to downdraught. Convectors placed close to the facade can prevent this but they will cause an increased energy consumption. Recent research has shown that the risk of thermal discomfort due to downdraught can be reduced by structural measures. Laboratory experiments have shown that large obstacles, such as the structural system of a glazed facade, which is placed in the cold boundary layer, can reduce downdraught considerably. This paper deals with the ability of Computational Fluid Dynamics to predict downdraught at a plane wall and at a wall with large obstacles. Quite simple boundary conditions were used in this study. Predictions of the main flow characteristics and the velocity levels in the occupied zone showed reasonable results.

INTRODUCTION

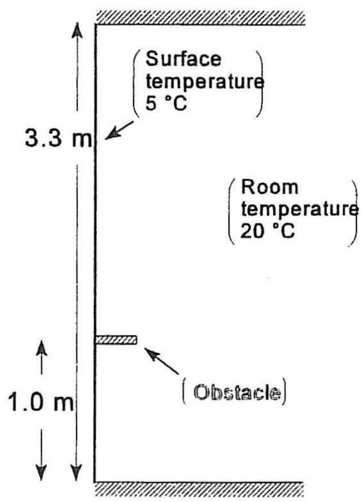
Glazed facades and atria have become popular as architectural features in building design. They are found in many types of buildings, e.g. office buildings, hotels, hospitals and shopping malls. In cold regions they give people the opportunity to perform their daily activities in a naturally lit environment away from the negative effects of a long and cold winter. The use of an atrium can create a thermally compact building where heat loss from the parent building is reduced and passive solar energy - gained in the atrium - is utilized. Furthermore, both glazed facades and atria can improve the usability of the daylight by allowing it to penetrate deep into the building in the adjacent rooms and by that reduce the need for electric light. In winter, however, glazed surfaces in buildings in cold regions are often the cause of thermal discomfort, partly due to cold radiation effects and partly due to downdraught problems caused by cold natural convective flows along the surface. For glazed surfaces the most critical problem is downdraught.

A reduction of the cold natural convective flow can be obtained by increasing the surface temperature of the glass or by neutralizing the flow with a warm air flow in the opposite direction. The surface temperature can be increased passively by reducing the heat loss through the window (more layers of glass, gas filling, low emission glass). The surface temperature can be increased actively by heating the surface with warm air from convectors close to the surface, alternatively by radiant heat or by electric heating of the glass. A cold convective air flow can be neutralized with a warm air curtain rising from convectors or supplied through ventilation slits. Common to all the active measures to avoid downdraught is the fact that they increase the energy consumption. This is due to the increase in the interior surface temperature and because the active systems may be operating also during periods when general room heating is not needed.

Recent research by Heiselberg et al. 1994, 1995 has shown that using the structural system to act as obstacles in the boundary layer flow is a possible way to improve comfort conditions in the occupied zone in cases with downdraught at glazed facades. By that, the initial costs of a convector or a ventilation system could be saved and the energy consumption could be reduced. It was shown that if the width of the obstacles was smaller than a critical width, a recirculation zone would be established below the obstacle and both the maximum velocity and the temperature difference were reduced. Thereby, the comfort conditions in the occupied zone were improved. If the width of the obstacles was larger than the critical width, the boundary layer flow would separate from the surface and a new boundary layer flow would be built up below the obstacle. In this case the comfort conditions in the occupied zone would not be dependent on the total height of the surface but only on the distance from the lowest obstacle to the floor. It was shown that the effect of the obstacles was dependent on the characteristics of the flow and on the size of the obstacle. A separation of the boundary layer flow from the surface in practical applications (relatively small critical width) required turbulent flow conditions. To improve the probability of turbulent flow conditions a distance of more than 2 m between the obstacles was necessary.

In this work the main emphasis has been put on the ability of a Computational Fluid Dynamics code to predict the main flow characteristics at a wall with large obstacles and the velocity distribution in the occupied zone. The work shows how far it is possible to get without using sophisticated turbulence models and wall functions and it is used as a starting point for more detailed calculations.

SPECIFICATION OF THE PROBLEM



The case studied in this paper is a cold wall placed in stagnant surroundings. The wall is 3.3 m high. A horizontal obstacle is placed 1.0 m above the floor and the width of the obstacle can be varied from 0.05 to 0.25 m. The experimental set-up has two-dimensional boundary conditions and all CFD-calculations are 2D calculations.

TEMPERATURE BOUNDARY CONDITIONS

The flow along the wall is fully buoyancy driven, so heat conduction through the wall is essential to the obtained flow field. It is possible to handle the temperature boundary at different levels of increasing complexity. The simplest approach, seen from the programmer's point of view, is to prescribe the heat flux at the surface and by that, indirectly incorporate radiation and heat conduction. This method should be expected to be too simple because the estimates of the heat flux may involve severe uncertainties as they are performed without detailed knowledge about the local air flow.

A description of the heat flux as a function of local flow parameters gives further improvement. If a measured temperature distribution is prescribed at the surfaces, the task narrows down to calculating convective heat transfer coefficients, α_w. The traditional and widely used method for this calculation is the logarithmic wall function formulated by Launder and Spalding 1974, assuming an analogy between momentum and energy transport.

The weaknesses of this type of wall function are shown by several authors, e.g. Chen 1988, Yuan et al. 1992 or Takemasa et al. 1992. It very well agrees with the exact solution for $y^+ > 30$ while the approximation in the range $8 < y^+ < 30$ is insufficient. A second drawback is that the wall function is developed for high Reynolds number forced convection, and wall heat flux cannot be exactly accounted for in mixed or natural convection flow. Furthermore, the traditional wall function is very grid dependent, which causes decreasing convective heat transfer coefficients with increasing distance from the wall to the first grid point in the flow domain. Methods for adjusting the traditional wall functions have been suggested by a number of authors.

Chen 1988 who works with indoor air flow improves the performance of the original wall function by curve fitting. A logarithmic curve segment is introduced to represent an intermediate buffer layer between the laminar and the turbulent region. The extra curve segment substitutes the traditional wall function in the range $8 < y_+ < 40$. The wall function proposed by Yuan et al. 1992 is a four-layer model which incorporates the variation of σ_t with y^+.

This paper deals with air velocities obtained in the occupied zone being results from different sizes of obstacles placed on the cold wall. Calculations were made by the FLOVENT code version 1.4. The code has a built-in temperature wall function that is simpler than the advanced three and four layer wall functions mentioned above. In addition, using a simple fixed heat flux boundary condition at the wall is possible. To investigate the effect of the temperature boundary condition and grid dependence we studied a smooth wall with no obstacles.

Figure 1 shows the heat flux calculated by the wall function and the horizontal velocity distribution in the occupied zone at various grid sizes and a temperature difference of 15 °C between the wall and the room air. The figure shows that the calculated heat flux is strongly grid dependent with values varying from 34.7 W/m² at 17 mm to the first grid node, and to an upper value of 61.0 W/m² at 0.7 mm to the first grid node. In spite of this large variation in heat flux, the calculated horizontal velocities in the occupied zone are not very much affected. All curves, but the two curves at 11 and 17 mm grid node distance are very close to each other. They are diverging less than 10% from the experimental results presented by Heiselberg et al. 1995.

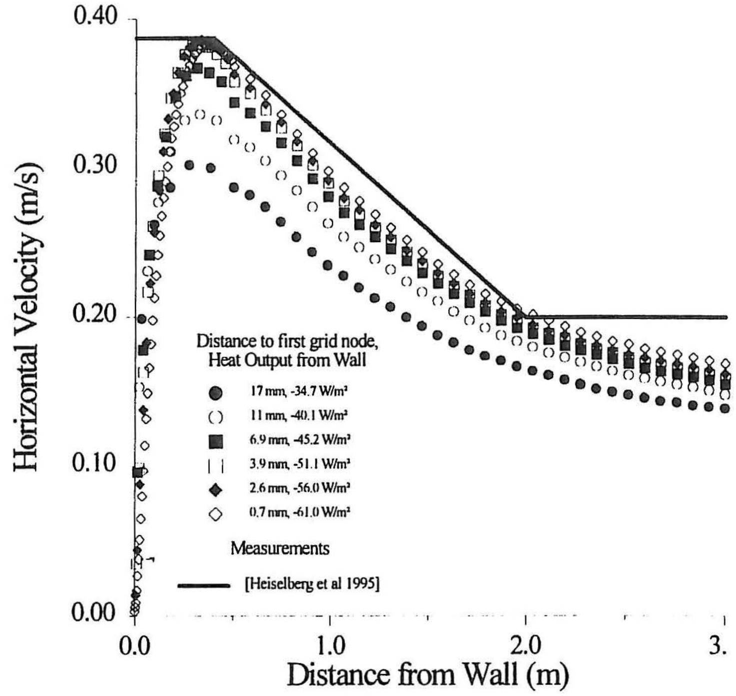


Figure 1. Horizontal velocity distribution in the occupied zone at various grid sizes and heat fluxes.

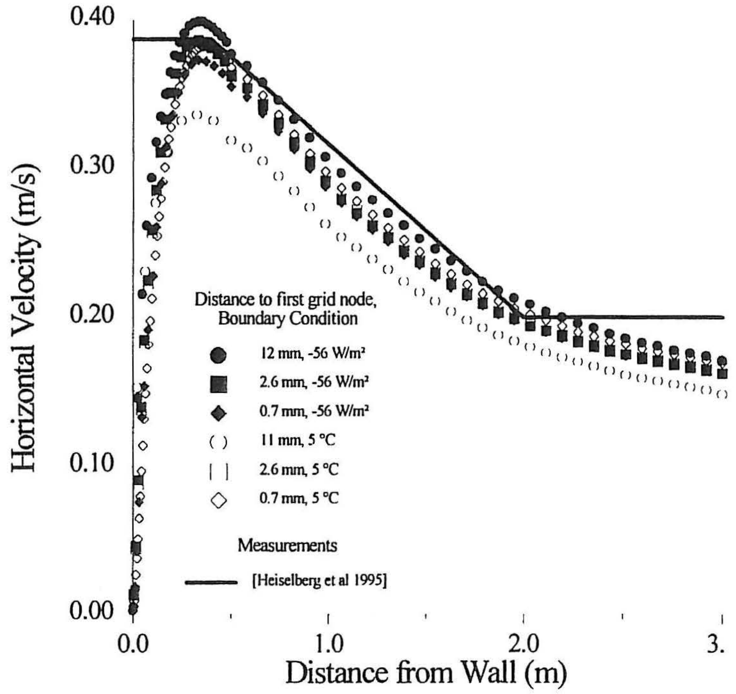


Figure 2. Horizontal velocity distribution in the occupied zone at various grid sizes and heat fluxes or temperature boundary conditions.

This leads to the assumption that a fixed heat flux boundary condition would be sufficient for our calculations. In figure 2 the fixed *flux* boundary condition is compared with the fixed *temperature* boundary condition. The calculation of the fixed flux of 56 W/m² was based on the correlation: $Nu_x = 0.11Gr_x^{0.33}$ as described by Cheesewright et al. 1988. Figure 2 shows that the results from the fixed flux method are closer to the experimental results and less grid dependent than the temperature wall function. The results presented below are based on the fixed heat flux boundary condition.

RESULTS

Flow conditions below the obstacle are shown in figure 3 for calculations with five different widths of the obstacle varying from w = 0.05 m to w = 0.25 m. The boundary layer flow follows one of two characteristic air flow patterns depending on the width of the obstacle. The flow will either reattach to the wall quickly after it has left the edge of the obstacle, creating a recirculating flow immediately under the obstacle, or the flow will separate from the wall, following a vertical path while it mixes with the room air. In the latter case a recirculation zone will be created under the obstacle also, as it is seen in figure 4b, but a new boundary layer flow is allowed to be built up more or less undisturbed. Corresponding measurements by Heiselberg et al. 1995 for the calculated case ($Gr_L = 2.95 \cdot 10^{10}$) have shown a critical width of the obstacle of approximately $w_{cr} = 0.15$ m whereas these calculations suggest a value of approximately $w_{cr} = 0.2 - 0.25$ m.

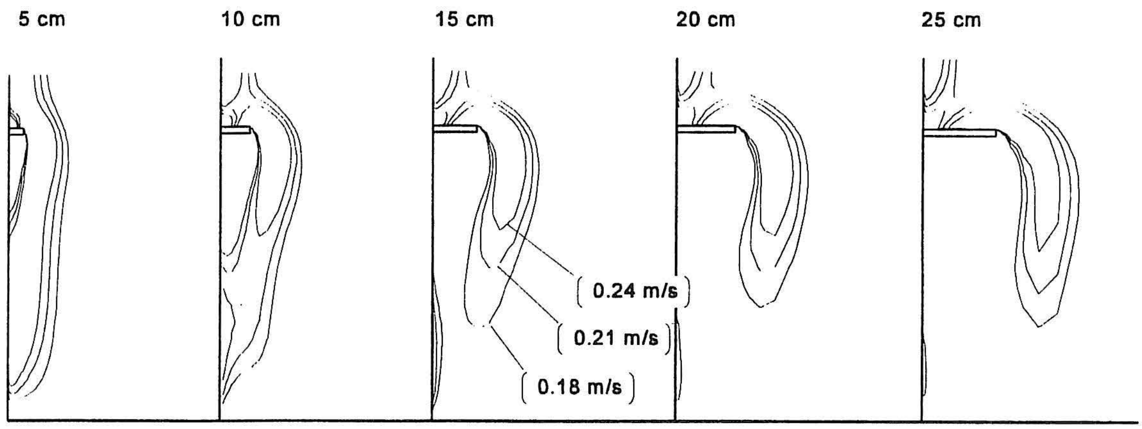
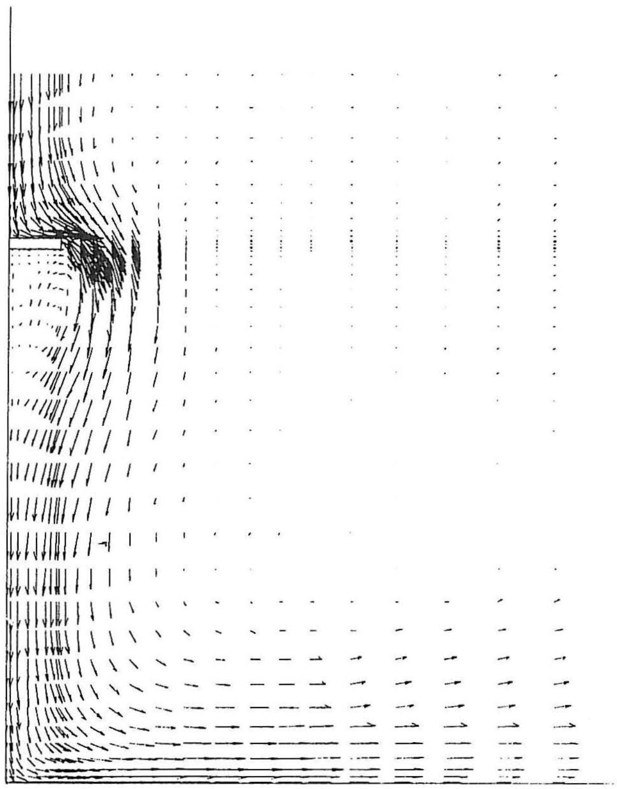


Figure 3. Isovels for air flow around a large obstacle on the wall.



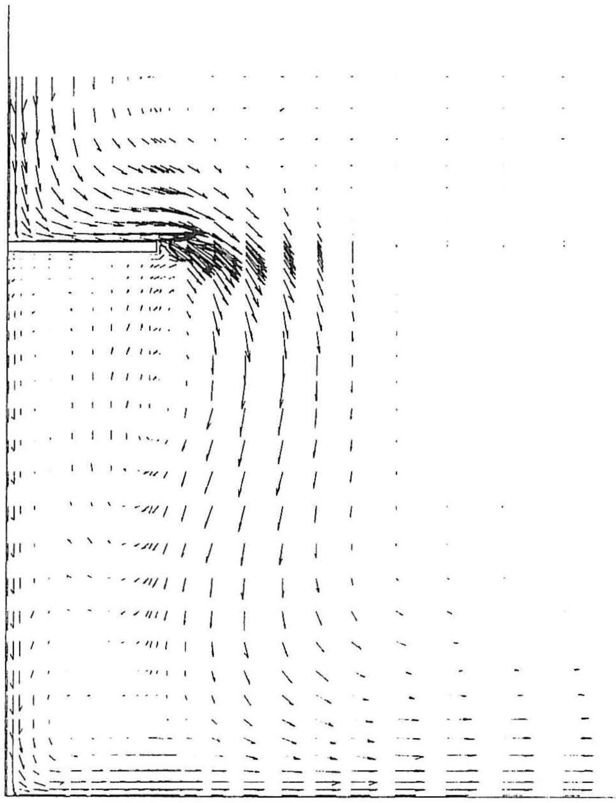


Figure 4. Air flow pattern around a large obstacle on the wall. A) Obstacle width 0.10 m. B) Obstacle width 0.25 m.

The height of the recirculation zone below the obstacle (h_R) depends on the width of the obstacle as shown on figure 5. The dependence is almost linear and can be expressed by $h_R = 2.35$ w. Measurements by Heiselberg et al. 1995 have shown recirculation heights of approximately 2.25 - 3 times the obstacle width.

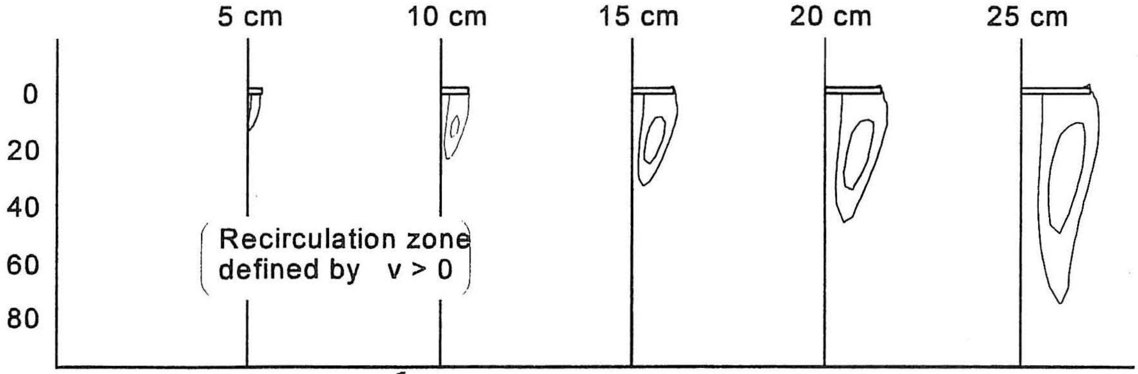


Figure 5. The recirculation zone below a large obstacle at the wall.

The presence of the obstacle on the wall should not influence the flow conditions at the wall only. It should also reduce the maximum velocities in the occupied zone caused by the boundary layer flow and, thereby, reduce the risk of thermal discomfort because of cold downdraught. Figure 6 shows the velocities in the occupied zone as a function of the distance to the cold wall in four cases. One case with a plane wall and three cases with an obstacle of increasing width on the wall. It is seen that the presence of a small obstacle on the wall will have almost no effect on the flow in the occupied zone, while the presence of a large obstacle reduces the maximum velocity in the occupied zone considerably.

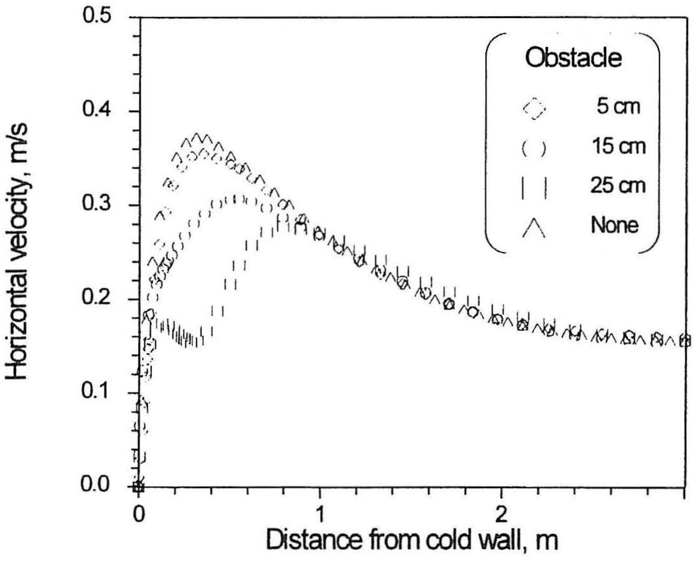


Figure 6. Horizontal velocity distribution in the occupied zone with obstacles of different sizes at the wall.

CONCLUSION

The present work has shown that it is possible to get quite far by CFD, in predicting comfort conditions in the occupied zone when downdraught from a cold wall is involved without using sophisticated turbulence models and wall functions.

The velocity distribution in the occupied zone, caused by downdraught from a plane wall, can be predicted within an accuracy of 10% of the measured values.

The main flow characteristics at a wall with obstacles can be predicted as well as the expected reductions of the velocities in the occupied zone. However, the number of calculations does not allow a detailed evaluation of the accuracy.

ACKNOWLEDGEMENT

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REFERENCES

Cheesewright, R. and Mirzai, M.H., 1988
The correlation of Experimental Velocity and Temperature Data for a Turbulent Natural Convection Boundary Layer. Proc. 2nd UK National Conference on Heat Transfer, Glasgow, pp. 79-89.

Chen Q., 1988
Indoor Airflow, Air Quality and Energy Consumption of Buildings, PhD thesis, Technicsche Universiteit Delft.

Heiselberg, P., Overby, H., Bjørn, E., 1994
The Effect of Obstacles on the Boundary Layer Flow at a Vertical Surface. Presented at the 5th Annex 26 Expert Meeting in Leamington Spa, UK, Aalborg University, Denmark, ISSN 0902-7513 R9454.

Heiselberg, P., Overby, H., Bjørn, E., 1995
Energy Efficient Measures to Avoid Downdraught from Large Glazed Facades. Accepted for publication in ASHRAE Transactions, Vol. 101.

Launder B.E., Spalding D.B., 1974
The Computation of Turbulent Flows, Computational Methods of Applied Mechanical Engineering 3.

Takemasa Y., Kurabuchi T., Kamata M., 1992
Numerical Simulation of Indoor Air Temperature and Wall Heat Flow Distribution of a Heated and Cooled Room. Proceedings of the International Symposium on Room Air Convection and Ventilation Effectiveness, Tokyo.

Yuan X., Huber, A., Schaelin, A., Hachmann, P., Moser, A. 1992.
New Wall Functions for the Numerical Simulation of Air Flow Pattern in Rooms, Proceedings of ROOMVENT'92, vol.1, Aalborg.

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